# A Study on the Fatigue of Fiber Glass Reinforced Polyvinylchloride and it's Microstructure

Hiroshi KIMURA,* Takuzi YAMAGUCHI,*
Masakazu TSUBOKAWA,* Koichi NISHI,*

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In this paper we describe an experimental study on the fatigue mechanism of fiber glass reinforced polyvinylchrolide. The experiment material was a heat-press molded composite material of two layers of polyvinylchrolide, with chopped strands of glass (200 mono-fibers of glass of 50 mm. long) spread at random in between.

## INTRODUCTION

Fiber reinforced thermoplastic (F.R.T.P.), the reinforced engineering plastic, has attracted special interest recently as a material for the public nuisance preventing equipment. Composite material of polyvinylchrolide and F.R.P. makes good use of the respective excellent anti-corrosive property and high mechanical strength, and is produced as F.R.V. or G.R.V.

However, little is known as to fatigue strength of such F.R.T.P. when it is used as anti-corrosive structural material of high polymer for strength member of the public nuisance preventing equipment or for chemical plant, despite such fatigue strength is essential for designing. This article deals experimentally with fatigue mechanism of fiber glass reinforced polyvinylchrolide.

## EXPERIMENTAL RESULTS AND CONSIDERATION

The experiment material was a heat-press molded composite material of two layers of polyvinylchrolide, with chopped strands of glass (200 mono-fibers of glass of 50 mm. long) spread at random in between. The dumb-bell shaped test pieces as shown in Fig. 2 were prepared for experiment from the above-mentioned experiment material. Cantilever plane-bending fatigue testing machine in compliance with ASTM's requirements for Type-A testing machine was made for the experiment. An eccentric disc with a crank is fitted loosely on flywheel shaft of the testing machine, and the amplitude can be varied by turning the disc. Measurement of glass content in the F.R.T.P. used for the experiment was carried out in the following procedures:

(i) Measurement of the specimen weight.

* Dep. of Textile Eng.

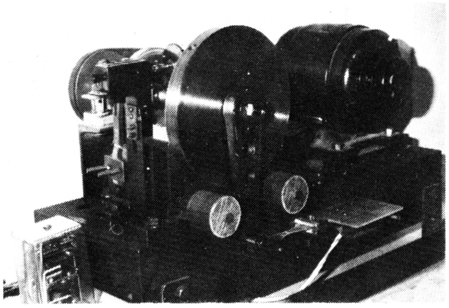


Photo. 1 Fatigue testing machine

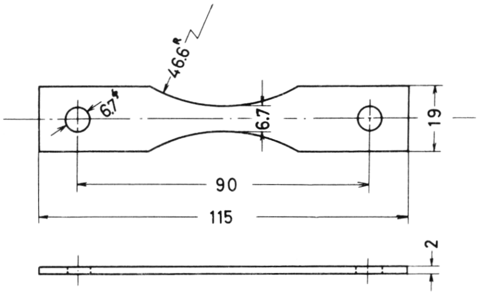



Fig. 2 Test Specimen

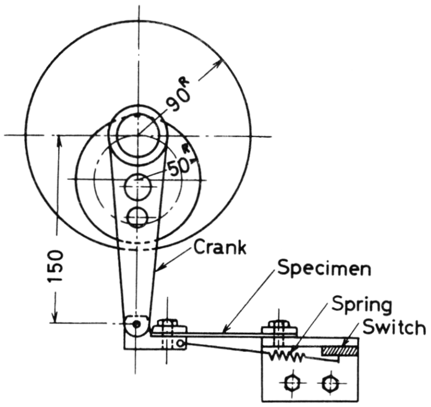



Fig. 1 Fatigue testing machine (Principal part)

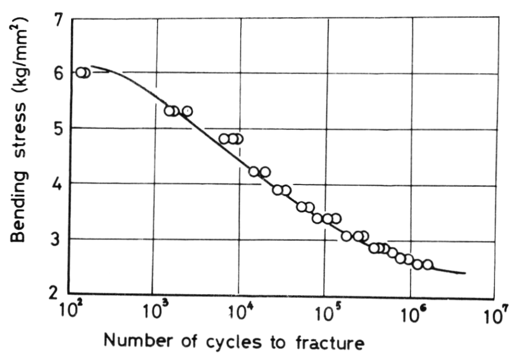



Fig. 3 S-N curve

(ii) Separation of P.V.C. from glassfiber after resolution by heating in cyclohexanone solvent.

(iii) Determination of glassfiber weight after washing and vacuum drying of glassfiber.

Fig. 3 shows the characteristic S-N curve of bending fatigue of fiber glass reinforced P.V.C. obtained through the experiment. From the result of the experiment, fatigue strength of the composite material was known to be 2.5 $kg/mm^2$. Result of the previous study by the author had shown that the fatigue strength of engineering plastic is approximately 1/6 of the static bending strength, and the author has had a belief that this is the value to be adopted in designing when the plastic is used for strength member.

It has become clear after the experiment of this time that the static bending strength of fiber glass reinforced P.V.C. is 12.97 $kg/mm^2$ against the fatigue strength being 2.5 $kg/mm^2$, 1/5.2 of the former, thus the ratio of fatigue strength to static bending strength of engineering plastic can be applied as a general conception to fiber glass reinforced P.V.C. The author has in the second place investigated the correlation between the crack developed during the fatigue test and the number

Table. 1 Number of cycles at initiation of cracking (A) and number of cycles at fracture (B) (Bending stress : 3.42kg/$mm^2$)

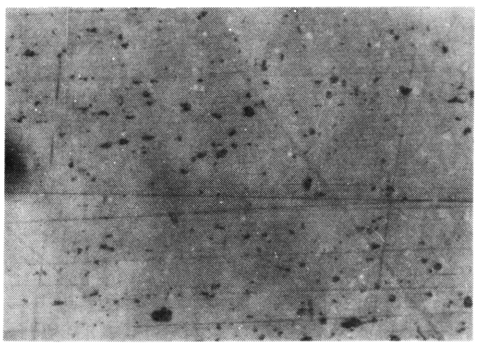
| | (A) | (B) |
|---|---|---|
| 1 | 23000 | 56500 |
| 2 | 65000 | 82500 |
| 3 | 37000 | 87600 |
| 4 | 24100 | 71500 |
| 5 | 55000 | 109800 |

of repetitions until the breakdown due to fatigue. In other words, the correlation between the number of repetitions until the crack always develops instantaneously in the matrix layer and the number of repetitions until the breakdown due to fatigue has been inquired. Table 1 shows the result of the experiment in which the correlation between the number of repetitions until a crack develops under bending stress of 3.42 kg/$mm^2$ and the number of repetitions until breakdown.

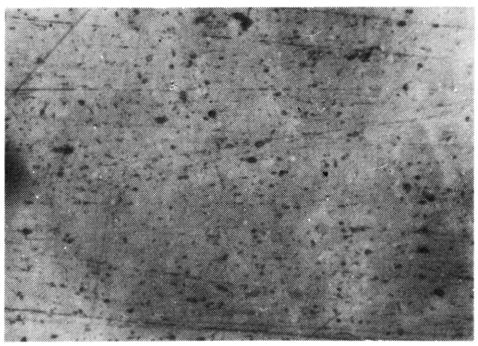
Crack developed first on either upper or lower matrix layer, then on the reverse matrix layer. The mechanism of development of such crack may be explained by the following assumption ; viz. adhesion of glassfibers in the strand starts to break away in the first place, which then causes glassfiber layer to break away from the matrix layers.

The constitution of composite material is thus destroyed in the second place at the locality of such breaking-away, and the strength is lowered eventually. Observation of the part of breakdown shows variations in overlapping condition and direction of strands, and there appeares little correlation between the number of repetitions at which a crack develops and the number of repetitions at which the material breaks down. Namely, as the overlapping of the strands at the part of the crack becomes greater or the arrangement of the strands comes closer to right angle to the direction of the crack, more number of repetitions is required from the development of a crack until breakdown.

Photo. 2 show surface conditions of (a) before the fatigue test and (b) after bearing repeated fatigue of 12,000 times under the bending stress of 4.23 kg/$mm^2$. Very little difference can be seen in these pictures, and no crack has developed

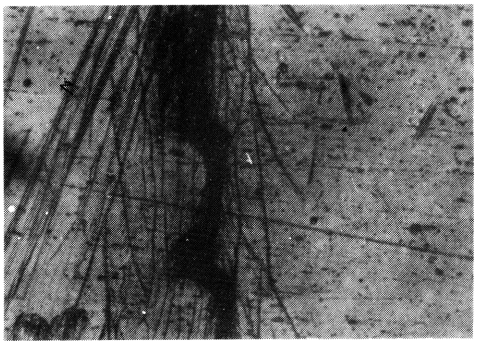


(a) Before fatigue testing

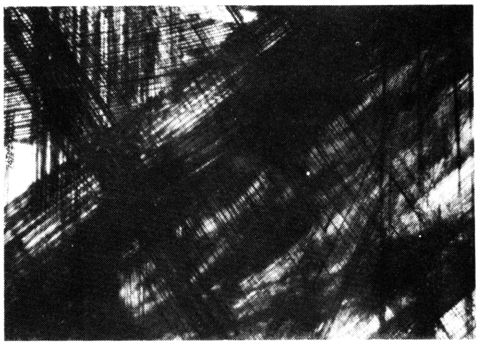


(b) At 12000 cycles after fatigue testing (Bending stress : 4.23kg/$mm^2$)

Photo. 2 Surface appearances of test specimens



(a) Surface appearance



(b) Condition of strands

Photo. 3 Photographs of test specimen with fatigue cracking

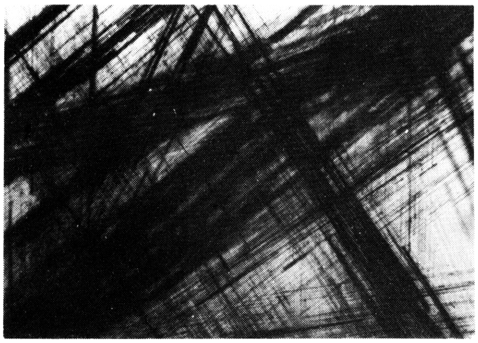


Photo. 4 Condition of strands before fatique testing

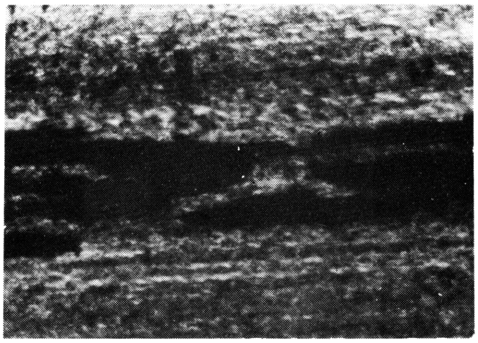
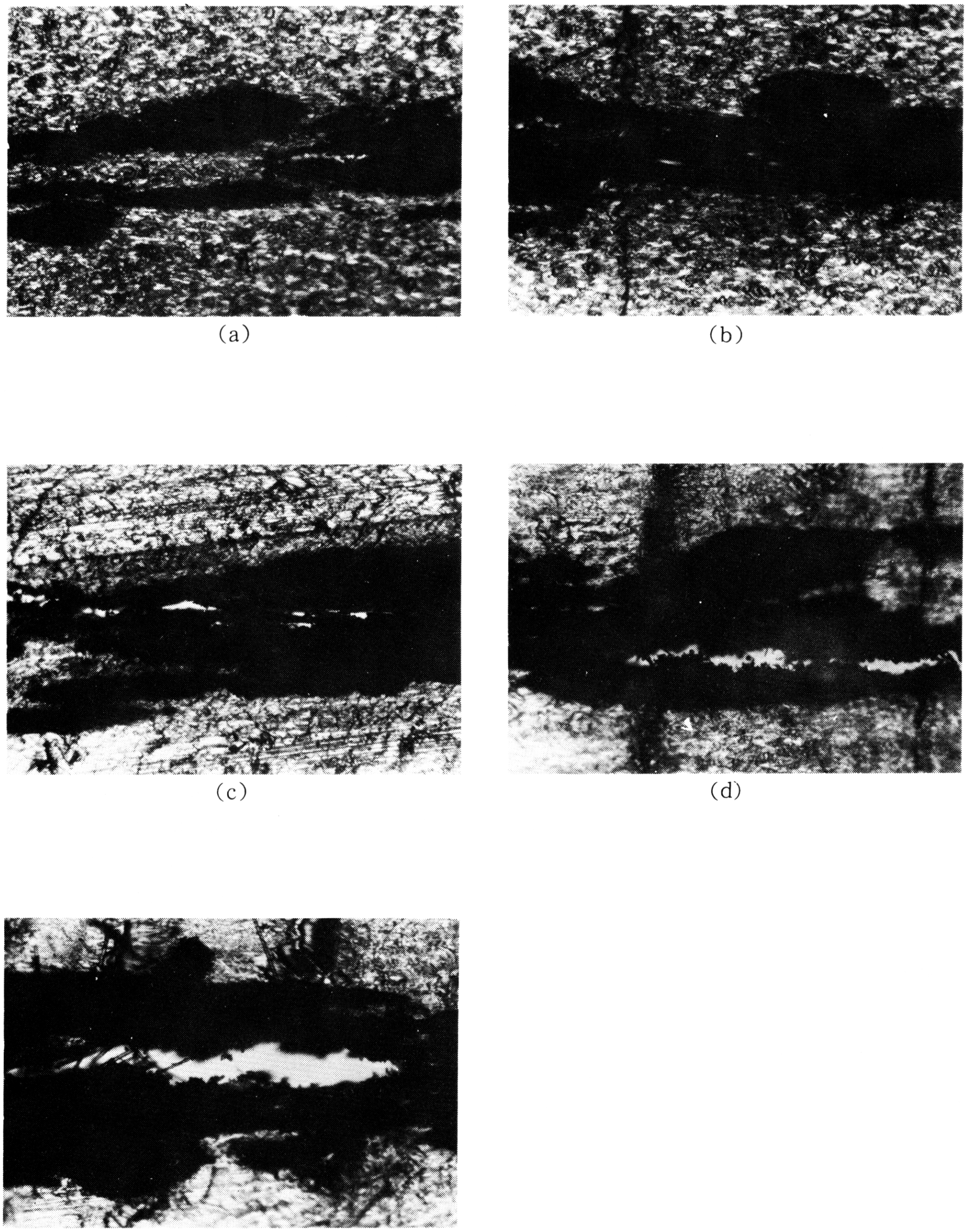


Photo. 5 Section of specimen before fatique testing

yet.

Photo. 3 show (a) the surface when a crack developed instantaneously in matrix layer and (b) the specimen seen through the light.

Instantaneously with development of a crack, the specimen becomes white at the part of the crack, and it has been confirmed that such whitening is due to breaking-away of the matrix layer from the strand layer. Photo. 4 shows the condition of strands before fatigue test, and the black and bold streak indicates insufficiently adhered and converged glassfibers. When the distribution of glassfibers in the strand is localized, there must be unevenness in adhesion condition, and this might be one of the reasons why the correlation between the crack development and the breakdown is so scanty. Photo. 5 shows the section of the specimen before fatigue test. Black part in the center is strand and is veloped in matrix. Photo. 6 is a microscopic cross section observation the adhesion condition of matrix and strand layers in the course of fatigue test under bending stress of 3.42 $kg/mm^2$. From this experiment, it has become clear that the breaking-away develops as a void in the strand layer only after considerable accumulation of fatigue, and that a crack develops on the surface, or matrix layer, of the specimen immediately after occurrence of breaking-away.



(a) (b) (c) (d) (e)

Photo. 6 Propagation of peeling in strands

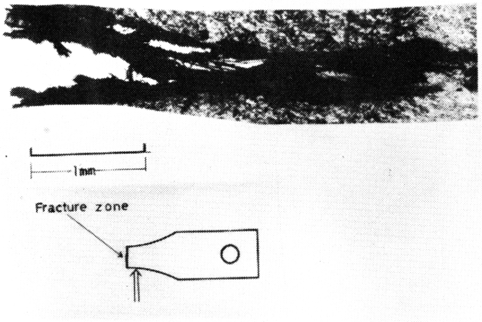



Photo. 7 Section of fracture zone

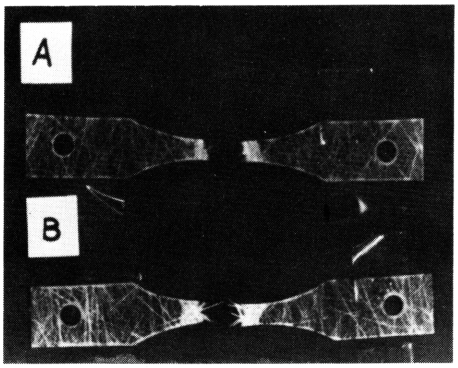



Photo. 8 Fracture of specimen after tensile test

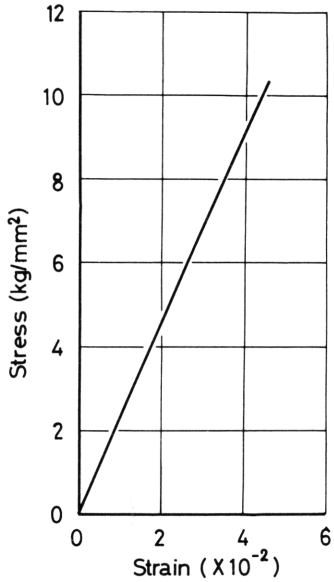



Fig. 4 Stress-strain curve

In other words, it has been confirmed that there occurs breaking-away in the strand in the first place, then the strand layer breaks away from the matrix layer, and lastly a crack develops on the matrix layer instantaneously with whitening. It requires considerable number of repetitions further from the time of partial break-down in the vertical direction of the strand layer until the breakdown, and this shows that the strength of glassfibers itself works as considerable resistance. Photo. 7 shows edge of the broken-down part, from which it is noted that the void due to breaking-away in the strand spreads twofold or threefold within 2-3mm, from the broken-down surface. Bending stress applied in this instance was 4.23 $kg/mm^2$, but when smaller stress is applied and more number of repetitions is required from development of a crack until breakdown, then the range in which void appears becomes wider. In order to observe in the next place the process of fatigue progress, tension test has been carried out to find how the condition of matrix layer changes and how the relation between matrix layer and glassfiber layer changes as the fatigue advances. Photo. 8 show results of tension test before the specimens were fatigue-tested; A shows the specimen to which the tension of 10.15 $kg/mm^2$ was applied, while B 7.09 $kg/mm^2$. Specimen appeared in picture A broke down in the form that glassfibers themselves were entirely cut, while specimen appeared in B broke down in such manner as glassfibers broke away from, and were rid of matrix. In other words, adhesion of specimen A was sufficient, while specimen B insufficient. Fig.4 is the stress-strain curve obtained through tension test on the specimen before fatigue, and it was confirmed that, in the tension test also, there occurs whitening first, then a crack in the matrix layer and lastly breaking-down. If the assumption that

(i) both the matrix and the strand resist the tension until a crack develops, but

(ii) once the crack develops, matrix takes no more partial charge in resisting tension and only the glassfibers have to stand against the tension,

is valid, then there should be an abrupt change in the stress-strain curve, which, however, cannot be recognized. This seems to mean that, in the tension test, the specimen breaks down instantaneously with the development of a crack in a different way from in the process of breakdown in bending fatigue test. Fig. 5-7 show the results of tension tests done on the specimens at different numbers of repetitions before breakdown in the course of fatigue tests under bending stress of 3.42, 4.23 and 4.82 $kg/mm^2$ respectively. By the way, the tension tests mentioned above were done on the specimens which developed no crack at such numbers of repetitions referred to above. In each case, the result shows the tensile strength falls gradually as the number of repetitions increases. This seems to be because of glassfibers being slipped and broken away one another in the strand and of consequent deterioration of the strand, since the strength of such composite material as this is maintained mostly by glaasfibers. In an attempt to find the correlation between the tensile strength of the specimen immediately after development of a crack and the tensile strength of the specimen that has had another 2,000 times in number of repetitions after development of a crack, another bending fatigue test has been carried out under the bending stress of 4.23 $kg/mm^2$, and the results are shown in Table 2. In each case, once a crack develops, tensile strength falls, since there is a breaking-away already in the strand and the specimen is no more a composite

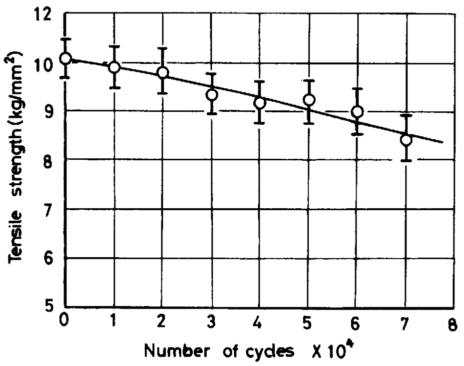



Fig. 5 Influence of number of cycles on tensile strength of specimen (Bending stress : 3.42$kg/mm^2$)

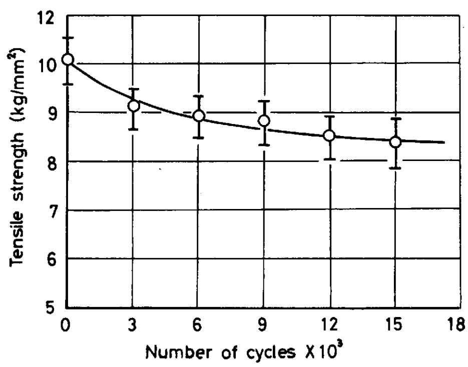



Fig. 6 Influence of number of cycles on tensile strength of specimen (Bending stress : 4.23$kg/mm^2$)

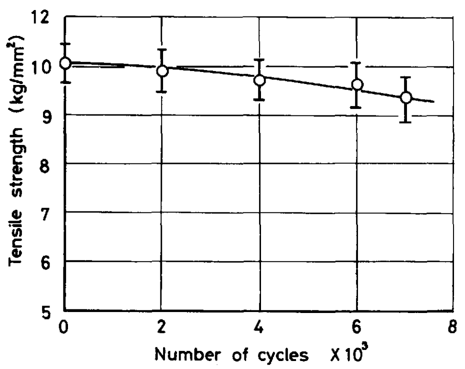



Fig. 7 Influence of number of cycles on tensile strength of specimen (Bending stress : 4.82kg/mm$^2$)

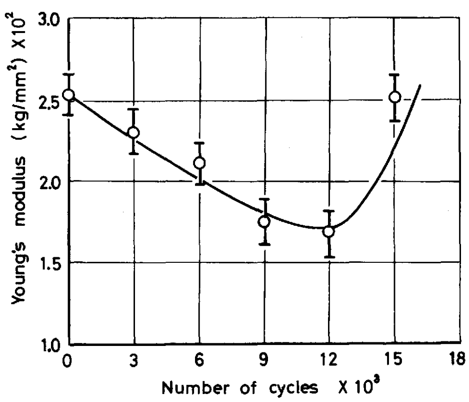



Fig. 9 Influence of number of cycles on Young's modulus of specimen (Bending stress : 4.23kg /mm$^2$)

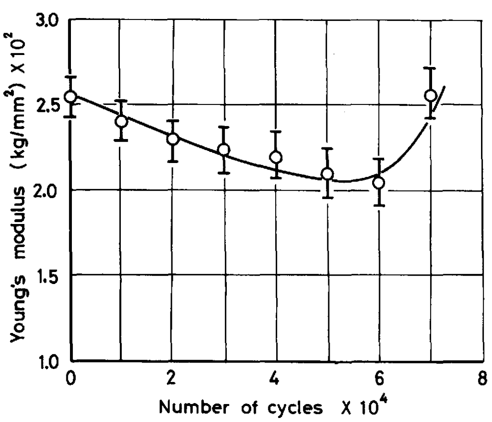



Fig. 8 Influence of number of cycles on Young's modulus of specimen (Bending stress : 3.42kg /mm$^2$)

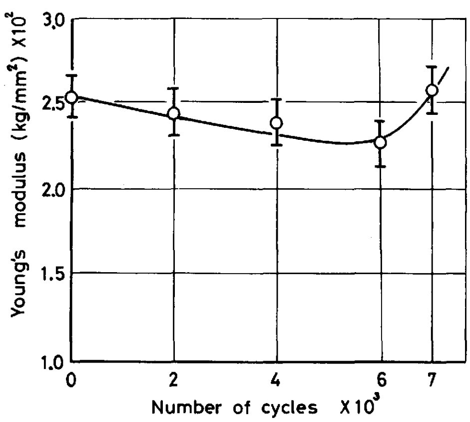



Fig. 10 Influence of number of cycles on Young's modulus of specimen (Bending stress : 4.82kg/mm$^2$)

material. As the number of reptitions increases after development of a crack, breaking-away in the strand grows further and void wider, inducing further fall in tensile strength. There appears a phenomenon of work hardening in the matrix layer as the fatigue advances, and although there is a tendency that elastic modulus becomes greater as the number of repetitions increases when considered on the matrix alone, the value of elastic modulus in bending fatigue test of the composite material decreases until the number of reptitions reaches 60-70% of the number of repetitions at which the material breaks down. In other words, up to 60-70% of the number of repetitions, decrease in elastic modulus on account of slip and breaking-away of glassfibers in the strand is more influential than increase in elastic modulus by hardening of the matrix. After the number of repetitions exceeds 60-70%, hardening of the matrix layer becomes greater, and elastic modulus of the composite

Table 2 Tensile strength of test specimen at initiation of cracking (A) and at 2000 cycles after initiation of cracking (B) (Bending stress : 4.23kg/mm²)

| (A) kg/mm² | (B) kg/mm² |
|---|---|
| 5.36(16500) | 4.57(18800+2000) |
| 5.47(16600) | 4071(12500+2000) |
| 6.25(17700) | 4.03(17100+2000) |
| 6.57(11700) | 5.03(13000+2000) |
| 5.81(15500) | 4.23(18100+2000) |

Table 3 Mechanical properties of materials used in the experiments

| Mechanical properties | Each values |
|---|---|
| Tensile strength ($kg/mm^2$) | 10.06 |
| Young's modulus ($kg/mm^2$) | 254.14 |
| Elongation (%) | 4.52 |
| Bending strength ($kg/mm^2$) | 12.97 |
| Bending modulus ($kg/mm^2$) | 370.85 |
| Fatigue strength ($kg/mm^2$) | 2.00−2.50 |

material increases, showing even the higher value in elastic modulus just before development of a crack than the value obtained before fatigue. Namely, development of a crack in the matrix is affected not only by the fall in strength because of breaking-away of glassfibers in the strand through bending fatigue, but also by work hardening, and a crack develops instantaneously.

## CONCLUSION

The foollowing summary can be made from the results of the present experiments.

Strength of the composite material against bending fatigue is 2.5 $kg/mm^2$, and the value of 1/5-1/6 of the bending strength may be used as common value to plastic materials in general. There is little correlation between the number of repetitions at which a crack develops and the number of repetitions at which the material breaks down. It is hard to observe by appearance how far the fatigue has progressed. Process of fatigue is that there occurs slip and breaking-away of fibers in the strand in the first place, then whitening phenomenon on account of breaking-away of the matrix and the strand layers, and the instantaneous development of a crack in the matrix. There has been, in this composite material, an unevenness in adhesion of glassfibers in the strand even prior to fatigue. Elastic modulus falls in the first place as the number of repetitions increases, then increases after the number of repetitions reaches 60-70% of the number of repetitions until the breakdown.

## ACKNOWLEDGMENT

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## REFERENCES

1) Hiroshi KIMURA : "Fatigue of Fiber Glass Reinforced Plastics", F.R.P Technical Society Vol. 10, No. 4, P. 201—207(1964).

2) F.R.P. Technical Society : "Reinforced Plastic Handbook",(1969).